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Summary Report

October 1973

Final Report Acquisition/ Expulsion System for Earth Orbital Propulsion System Study

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FINAL REPORT ACQUISITION/EXPULSION SYSTEM FOR EARTH ORBITAL PROPULSION SYSTEM STUDY

Approved

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Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

Prepared by

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FOREWORD

This document is submitted to the National Aeronautics and Space Administration, Johnson Space Center, in accordance with the Data Requirements Description of Contract NAS9-12182. The work was performed by Martin Marietta Corporation, Denver Division, under the technical direction of Mr. Larry R. Rhodes, Power and Propulsion Division, NASA-JSC, Houston, Texas. Mr. G. Robert Page, Mr. Dale A. Fester, and Mr. Raymond C. Tegtmeyer of Martin Marietta were Technical Directors for the following separate phase of the program--Cryogenic System Designs and Verification Tests, Earth Storable System Designs and Verifications Tests, and the Flight Test Article, respectively. This final report consists of five volumes as follows:

Volume I - Summary Report;

Volume II - Cryogenic Design;

Volume III - Cryogenic Test;

Volume IV - Flight Test Article;

Volume V - Earth Storable Design.

The following Martin Marietta personnel assisted Mr. Page: Messrs. K. C. Lunden, Ashton J. Villars, Sidney P. White, Ralph N. Eberhardt, Thomas E. Bailey and Robert O. Neff with the analysis and experimental work; Messrs. T. Richard Barksdale and E. Robert Wilson, design support; and Messrs. Andrew T. Pecarich, Jack S. Marino and Duane J. Brown with testing.

Mr. Fester was ably supported by: Messrs. James R. Tegart and Preston E. Uney for the parametric analysis; Glenn F. Holle, experimental work; and Dennis E. Gilmore, design.

Mr. Tegtmeyer's study phase was supported by Messrs. T. Richard Barksdale, Dennis E. Gilmore, H. Frank Brady, E. Robert Wilson and John E. Littlefield, cryogenic test article and ground vibration survey model designs; A. Bert Allerton, Paul J. Jones and James E. Nelson, structural design and dynamics; William E. Smull, communications; Duane J. Brown, instrumentation; Alvin E. Hargis, antenna design; Phillip B. Powell and James H. Masson, power; Richard P. Warren and Rex P. Moore, thermal control; Mervin Bauer, test planning; James W. Tuchton, quality assurance; Ray Horn and Larry J. Rose, ground support; Dale E. Calender, manufacturing; and Marvin P. Udevitz, systems engineering.

Test work under the contract was performed in the Propulsion Research Laboratory under the direction of Mr. H. Frank Brady.

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I. INTRODUCTION

The Martin Marietta dual-screen-liner (DSL) concept for the subcritical storage of cryogens during low-g was evaluated under an earlier NASA-JSC contract, NAS9-10480, to indicate its range of applicability, as summarized in Ref I-1. The cryogens considered in the parametric study were hydrogen, oxygen, nitrogen, and methane. The DSL was shown to be an attractive storage concept to provide efficient and reliable: (1) gas-free liquid expulsion, on demand; (2) tank pressure relief by venting vapor, as required; and (3) near-continuous bulk liquid control.

Under the 23-month program begun in August, 1971, and summarized here, the DSL tank/feedline concept was analyzed, designed, and ground-tested in three separate program phases. Designs were made for an integrated OMS/RCS storage system for a representative cryogenic orbiter, an Earth-orbiting vehicle using LO_2 for a dedicated OMS, and an integrated storage system for the main and secondary propulsion systems using LO_2 and LH_2. The latter used representative criteria and guidelines for the fully-reusable Space Tug. The analyses and designs are detailed in Volume II. Results for the ground tests, including bench test data, KC-135 test data, and performance demonstrations for the 63.5-cm (25.0-in.) dia DSL model using LH_2 and LN_2 as the test liquids and GH_2 or GHe as the pressurant, are presented in Volume III.

The DSL tank/feedline design for the integrated OMS/RCS storage (LO_2 and LH_2) was recommended as the subscale flight test article for the long-term, orbital experiment planned and proposed under the second phase of the program. Two orbital test plans were formulated. One was based on a dedicated launch using an Atlas-F, with or without, an upper-stage. The second plan was based on using the cryogenic test module as a secondary payload. Both recommended LO_2 as the test liquid. The 7-day orbital experiment, as described in Volume IV, is needed to demonstrate liquid-free vapor venting, thus verifying the DSL design for incorporation into future, subcritical cryogenic storage applications.

The final phase of the program was used to analyze, design, and provide test data to support the passive acquisition/expulsion designs for the storage of earth-storable propellants during low-g. System/mission criteria and design guidelines used for this noncryogen study were representative of the OMS for the Space Shuttle orbiter. The results for this phase of the program are presented separately in Volume V.

II. PROGRAM OBJECTIVES

The objective of the three-phased program was to design and verify passive acquisition/retention devices for representative liquid propulsion systems for earth-orbiting vehicles. An emphasis was to be placed on experimental verification of the designs. One phase was to be limited to cryogenic propellants; a second phase, to earth-storable propellants. Under a third phase, orbital test plans were to be recommended for the complete verification of the passive DSL tank/feedline design.

III. PROGRAM STATUS AND SCHEDULES

Program objectives were satisfied in accordance with the schedule shown in Fig. III-1. The phases of the cryogenic and earth-storable propellant storage studies were similar in that Tasks I, II, III, and IV were used for analysis, design, testing, and development planning, respectively, for each phase. The development plans included both schedules and costs required to develop the DSL passive acquisition/expulsion device. The cryogenic plan was for the integrated OMS/RCS cryogenic tank and feedline design, whereas the earth-storable plan was for the representative OMS design. Development of the DSL included the orbital demonstration of liquid-free vapor venting needed to verify the design. Two different orbital demonstration programs were developed under Tasks V, VI, and VII. The latter tasks comprised the third phase of the program.

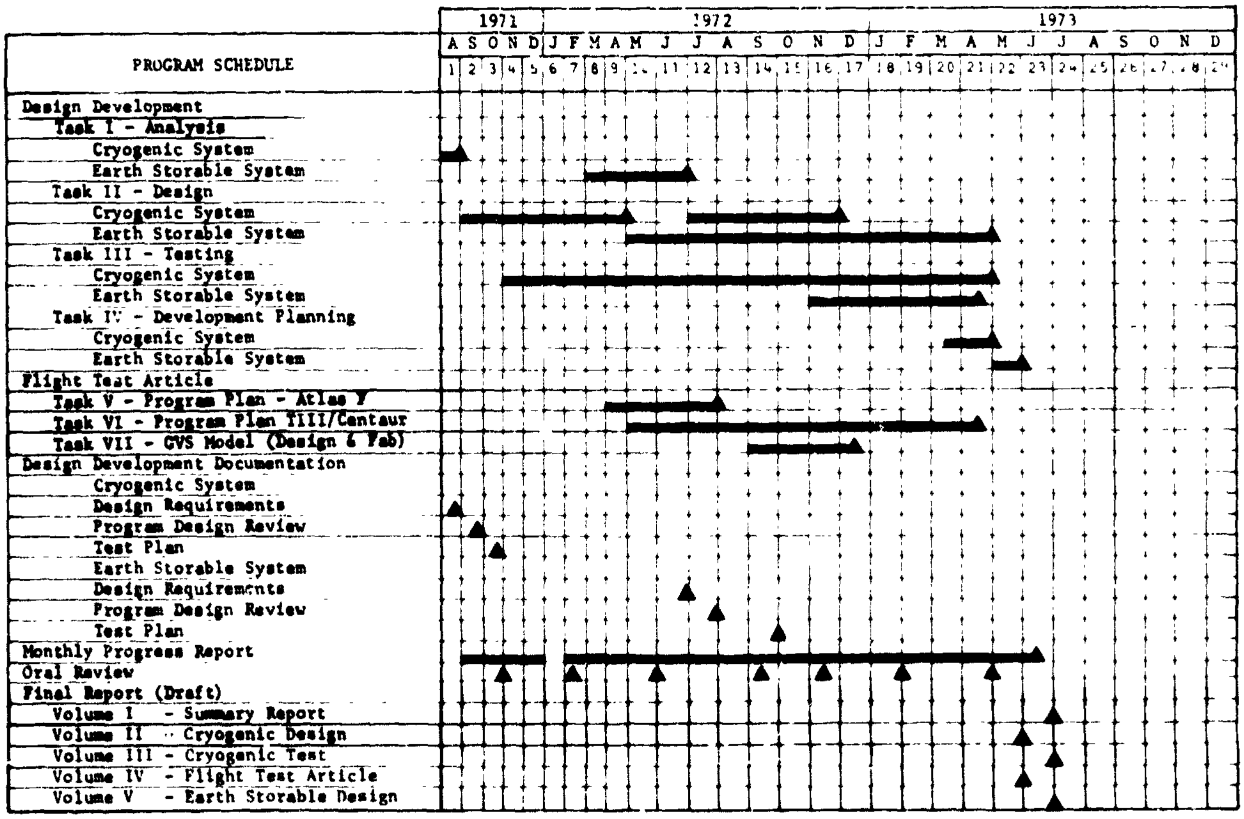


Fig. III-1 Program Schedule

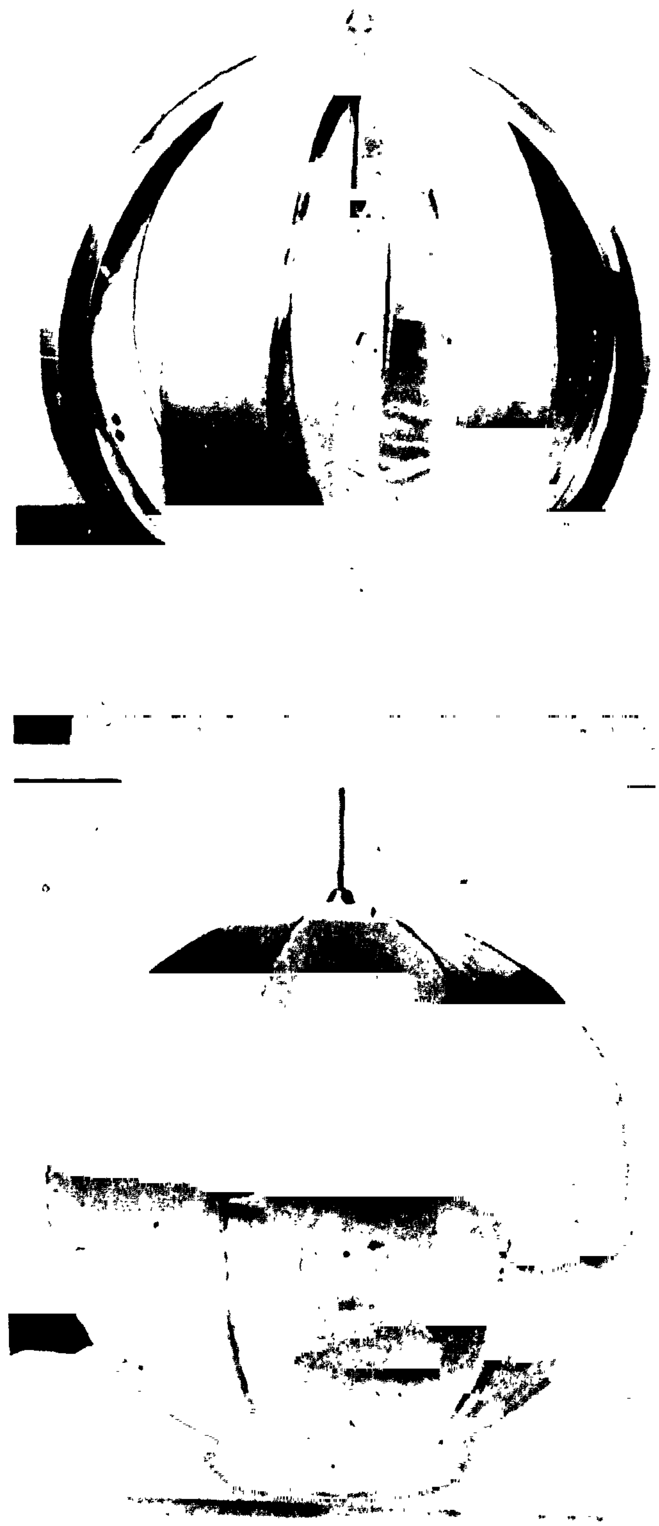
IV. TEST RESULTS

Ground test results for the cryogenic and earth-storable study phases were documented on 16-mm color film and are presented in Volumes III and V, respectively. The summary films can be obtained from Mr. Larry R. Rhodes, NASA-JSC.

The DSL device that was tested in the 63.5-cm (25.0-in.) dia tank using LN_2 and LH_2 as the test liquids is shown in Fig. IV-1. It has a complete 325x2300-mesh stainless steel screen liner that encloses the eight liquid supply channels. Two layers of 325x2300 screen were used to provide the liquid/vapor interface stability required for the minus 1 g testing and ensure passive communications between the two vapor regions in the tank (i.e., the central ullage and the annulus between the screen liner and tank wall).

Results for the boiloff, tank fill, and pressurization and LH_2 expulsion tests are presented in Table IV-1. Gas-free LH_2 was expelled during single, continuous withdrawals to depletion, and in four separate expulsions to depletion. Passive communication between the outer annulus and central bulk regions was successfully demonstrated by the liner. Tank loading was accomplished for both LN_2 and LH_2. The DSL device provided the predicted stable performance under both autogenous and GHe pressurization at temperatures of 89 to 278°K (160 to 500°R). System performance proved insensitive to tank pressure for tests between 13.7 and 31.0 N/cm^2 (20 to 45 psia). Although minus 1 g liquid-free venting was severely limited by the 1-g stratification phenomenon, the test data obtained do verify the venting of the DSL tank region.

One of the more pertinent test results for the ground tests conducted under the earth-storable study is the verification of the remote inspection technique required for the reusable orbiter OMS. The cylindrical screen device system used for the inspection tests is pictured in Fig. IV-2. Three different mesh sizes, 325x2300, 250x1370, and 80x700, were used as the single screen liner. Methanol was the test liquid. The inspection techique relies on wetting the screen device, trap, or liner so that the pressure retention (bubble point) can be verified using a controlled pressurization technique. Wetting of the screen may be accomplished using either the tank fill and drain lines or a spray nozzle incorporated in the tank.



a) Screen Channel Configuration

b) Total Screen Liner Covering Channels

Fig. IV-1 DSL Model for Demonstration Tests in 63.5-cm (25.0-in.) dia Tank

Table IV-1 Summary of 63.5-cm (25.0-in.) Diameter DSL Tank Tests

Boiloff Results

Test No.	Test Fluid	Tank Orientation	Heat Flux, W/m^2 (Btu/ft^2-hr)	Comments
1	LN_2	1 g	5.04 (1.6)	For Tests 1 and 2, high heat flux values were due to three uninsulated instrumentation cables.
2	LH_2	1 g	9.76 (3.1)	
3	LH_2	-1 g	5.67 (1.8)	The reduced heat flux was due to insulating the cables with 10 layers of aluminized Mylar.
4	LH_2	-1 g	6.93 (2.2)	Following Test 3, the electrical connectors leaked and were replaced with 1.27-cm (1/2-in.) stainless steel conduits. These conduits accounted for the increased heat flux value.

Fill Results

Test No.	Test Fluid	Tank Wall	Fill Rate, lpm (gpm)	Fill Time, min	Comments
1	LN_2	Cold	12.9 (3.4)	10	Successful fills were obtained under all conditions. The best approach for LH_2 is to fill at a low rate and also sub-cool LH_2 in the dewar before filling.
2	LH_2	Warm	3.4-4.91 (0.9-1.3)	25	
3	LH_2	Cold	7.56 (2.0)	17	
4	LH_2	Cold	2.26-3.02 (0.6-0.8)	45	

Pressurization and 1g LH_2 Outflow Results

Test No	Tank Pressure, N/cm^2 (psia)	Pressurization: Port Location	Pressurization: Gas	Pressurization: Temp, °K(°R)	No. of Expulsion Events	Expellable Liquid Outflowed	Comments
1	13.7 (20)	Bottom	GH_2	89 (160)	1	100%	For all tests except 9, outflow was successfully achieved by pressurizing through the diffuser in the tank bottom. Test 9 imposed severe pressurization conditions due to impingement of the pressurant directly on the screens. In Test 10 the periods between expulsion events were 5 to 10 minutes without venting. The ullage temperatures ranged between 21.1°K (38°R) and 51.2°K (92°R).
2	17.2 (25)						
3	24.1 (35)						
4	31.0 (45)						
5	17.2 (25)			278 (500)			
6	13.7 (20)		GHe	89 (160)			
7	17.2 (25)			89 (160)			
8	17.2 (25)	Bottom		89 (160)		100%	
9	17.2 (25)	Top	GH_2	89 (160)		97%	
10	15.1 to 22.0 (22 to 32)	Bottom	GH_2	89 (160)	4	100%	

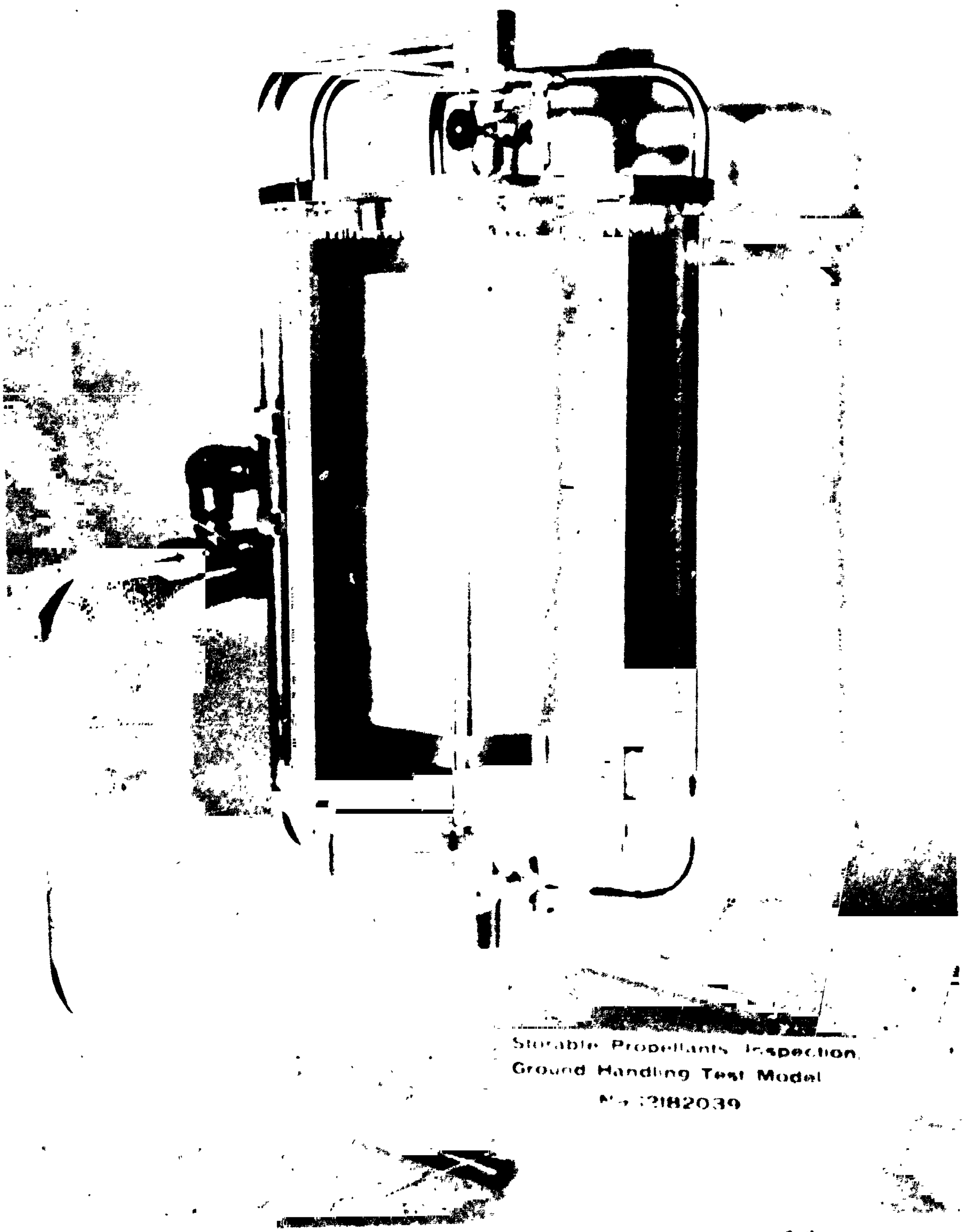


Fig. IV-2 29.2x43.2-cm (11.5x17-in.) Cylindrical Screen Model.

Typical of the test data is the pressure difference versus time plot, Fig. IV-3. Note that the pressure difference increases to a maximum value at which the pressurizing gas breaks through the wetted screen. This maximum pressure difference must satisfy the inspection requirement to prove that the passive device is flightworthy.

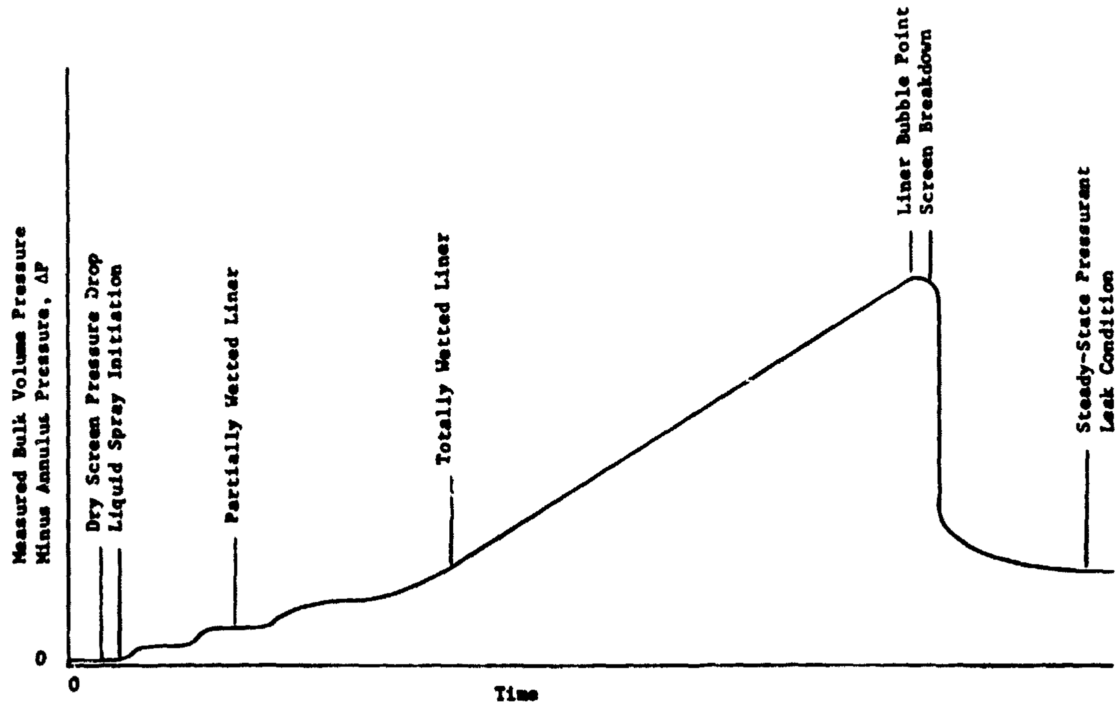


Fig. IV-3 Typical Data for Remote Inspection Technique

V. MANUFACTURING STATUS

Passive acquisition/expulsion devices for use with earth-storable propellants have successfully been flown. These included the Apollo SPS, Agena, Transtage, and the P95. The Mariner 9 bipropellant propulsion system also used a surface-tension design to provide gas-free liquid expulsion since the tank was launched upside down (i.e., the base of the standpipe was at the top of the spherical tank); the standpipe was an integal part of the bladder system.

Manufacturing experience has also been obtained from other capillary systems now being developed and from company-funded independent research and development programs. Fabrication of stainless steel screen devices is at a highly acceptable level. The DSL device pictured in Fig. IV-1 and the 1.78-m (70.0-in.) dia, 250x1370-mesh liner shown in Fig. V-1 are examples of stainless systems. The larger device was built in 1972 and is being tested during 1973 under a Martin Marietta IRAD program. As noted in Ref V-1 and Volume III, there are several acceptable forming and joining techniques for aluminum and titanium screen, as well as for stainless steel. There is considerably less experience for manufacturing fine-mesh screen devices using aluminum and titanium screen, but there do not appear to be any insurmountable problems.

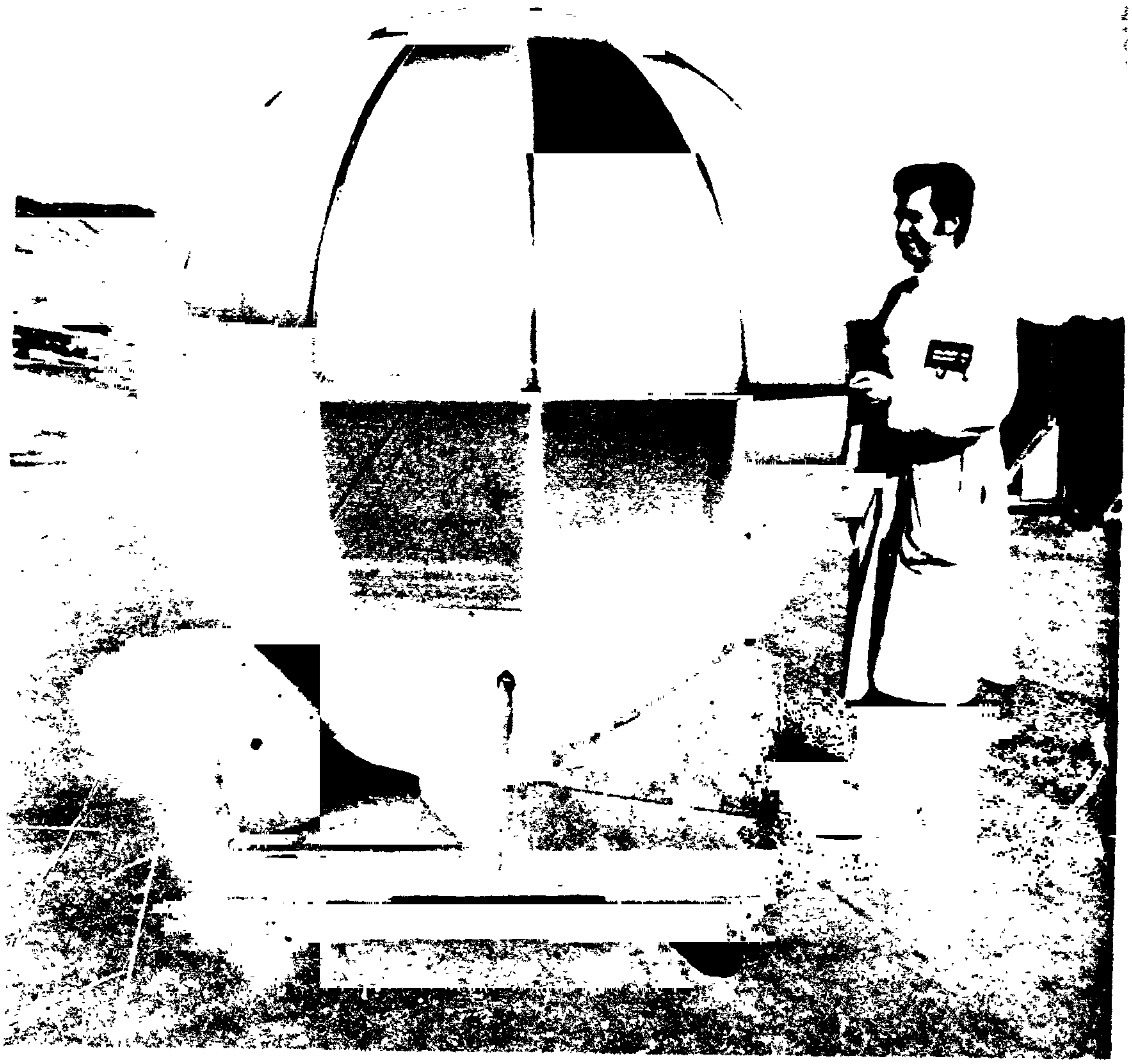


Fig. V-1 1.78-m (70.0-in.) Diameter Screen Device Fabricated under a Martin Marietta IR&D Program during 1972

VI. MAJOR TECHNICAL PROBLEMS AND RECOMMENDED SOLUTIONS

The major problem encountered during the program was the inability to completely verify the DSL tank design for the subcritical storage of cryogens by means of ground testing. The stratification problem, as discussed in Volume III, prevented minus 1g liquid-free gas venting during the LH_2 tests. The results of these tests are summarized in Table IV-1. Other tests reported in Volume III, such as the screen liner feedline, which is being worked under a separate Martin Marietta IRAD program during 1973 using LN_2 as the test liquid, presented certain design and procedural problems; however, only the stratification phenomenon was the major technical problem.

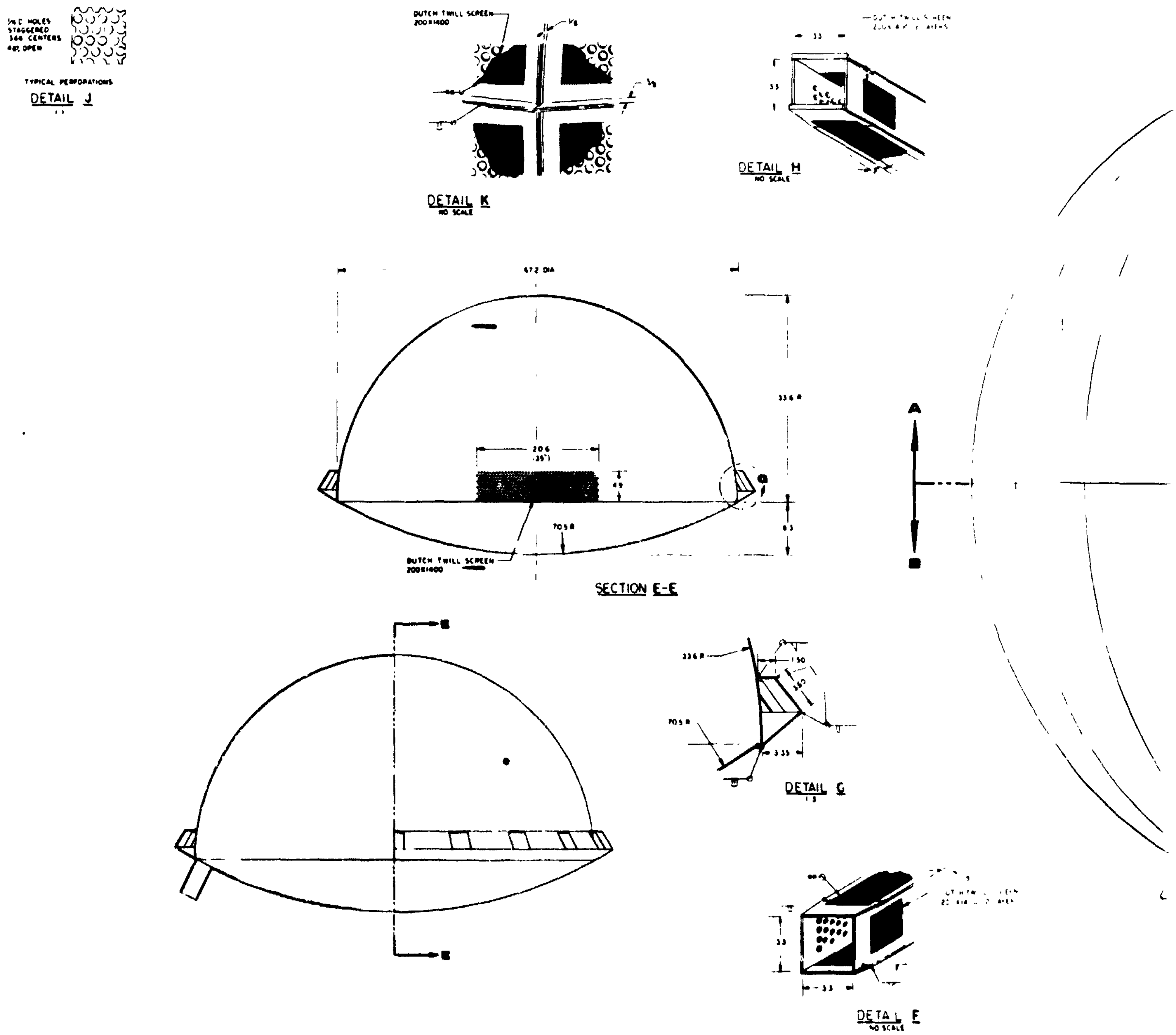
As discussed in Chapter VI, Volume II, development of the DSL design requires the successful demonstration of liquid-free gas venting. Based on the test results obtained during this program, no additional ground tests are recommended. Rather, two different orbital plans are proposed to satisfy the DSL development requirement. These plans are presented separately in Volume IV.

VII. THEORETICAL OR EXPERIMENTAL ANALYSES

Theoretical and experimental analyses for the cryogenic-propellant DSL acquisition/expulsion systems are presented in Volumes II and III, respectively. These analyses support the designs for the various earth-orbiting system/mission applications that were studied. The integrated OMS/RCS cryogenic design for the LH_2 tank is presented in Fig. VII-1 and VII-2; the small hemispherical trap device within the channel/liner is required to satisfy the RCS reentry requirement. The LO_2 design shown in Fig. VII-3 is for the representative dedicated OMS application. It has no trap since it does not have to satisfy the reentry requirement.

The passive propellant control designs for the fully-reusable cryogenic Space Tug are presented in Fig. VII-4 and VII-5. These designs are for LO_2 and LH_2, respectively. Each configuration has a small trap that is within the screen liner refilled during engine burns. The liner is needed to vent vapor to provide pressure relief.

The design analyses and experimental data for the earth-storable propellant storage designs needed to satisfy representative Shuttle orbiter OMS criteria and guidelines are presented in Volume V. One result of the parametric design analyses was the decision to categorize the various capillary propellant control techniques being considered in terms of the general range of applicability for each, as shown in Fig. VII-6. Note the extreme sensitivity of the passive designs to adverse accelerations that tend to disrupt the stability of the interface. Designs that rely upon capillary pumping to assure gas-free liquid expulsion on demand are generally practical only when adverse accelerations are less than 10^{-4} g. These devices lie to the left of the 10^{-4} g line. One typical design is that being developed by Martin Marietta for the Viking Orbiter propulsion system (Ref. VII-1). This system relies on capillary pumping and uses no fine-mesh screen.



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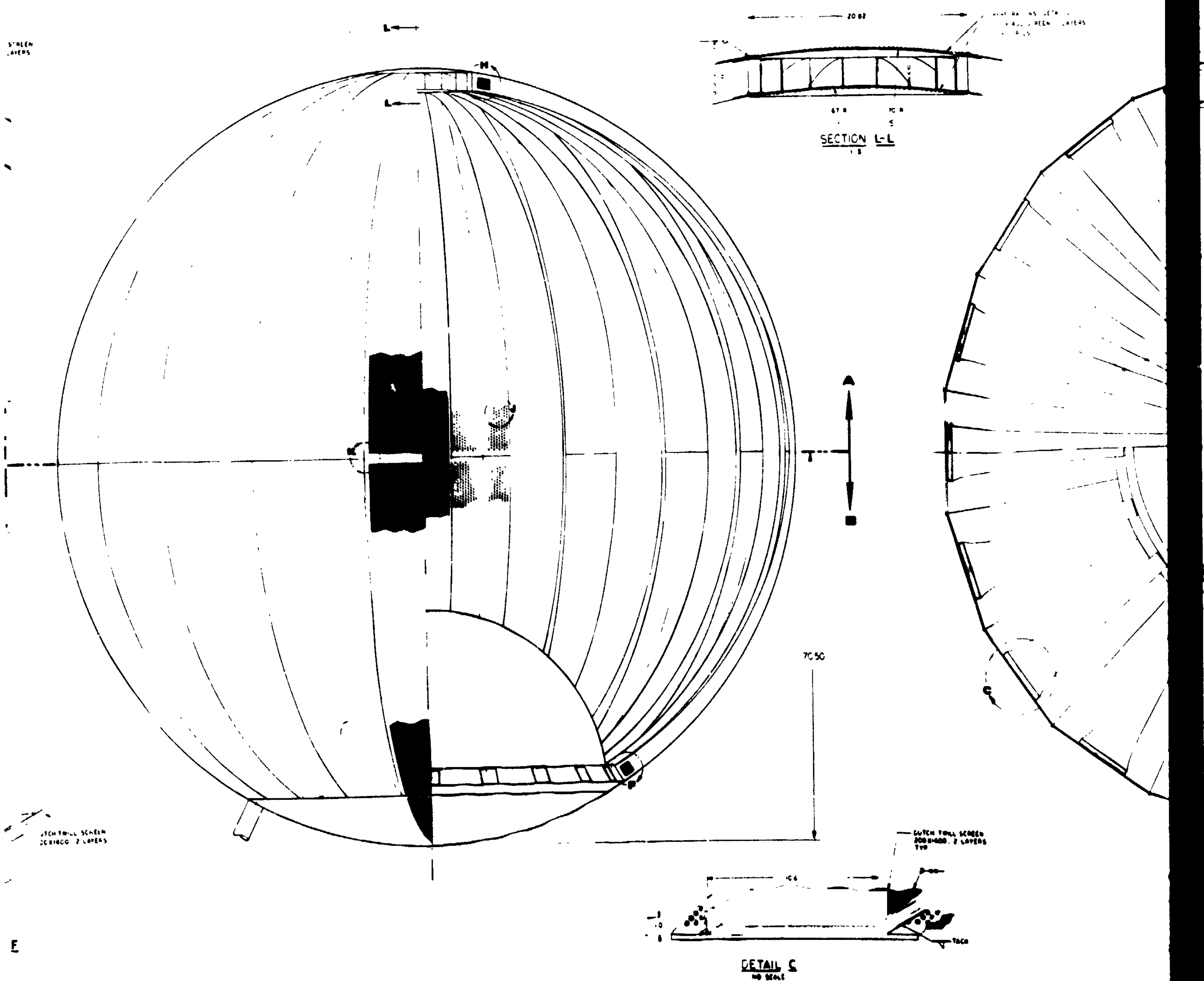

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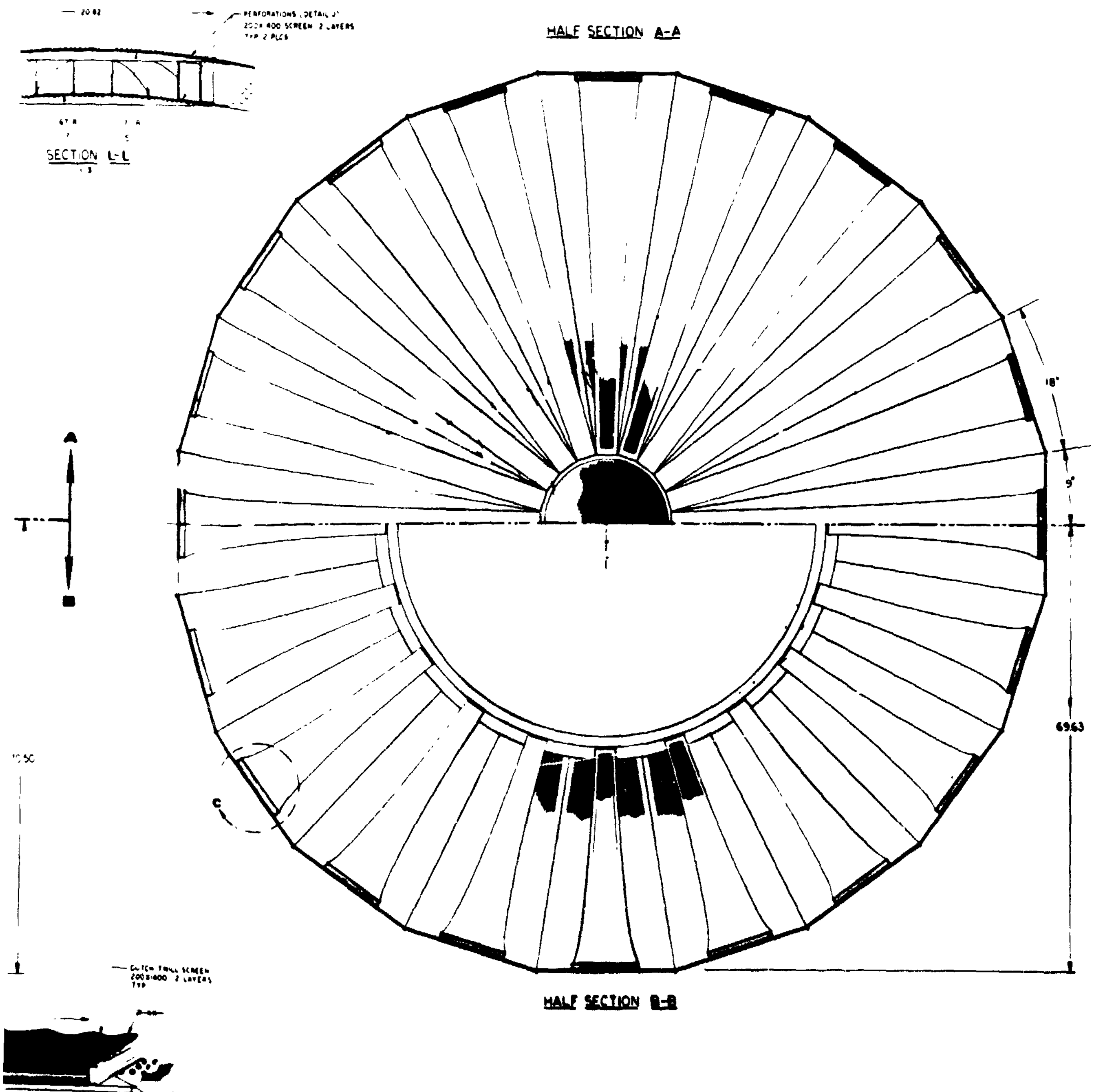

Fig. VII-1 Detail Design for LH_2 Acquisition/Exp..lsion System

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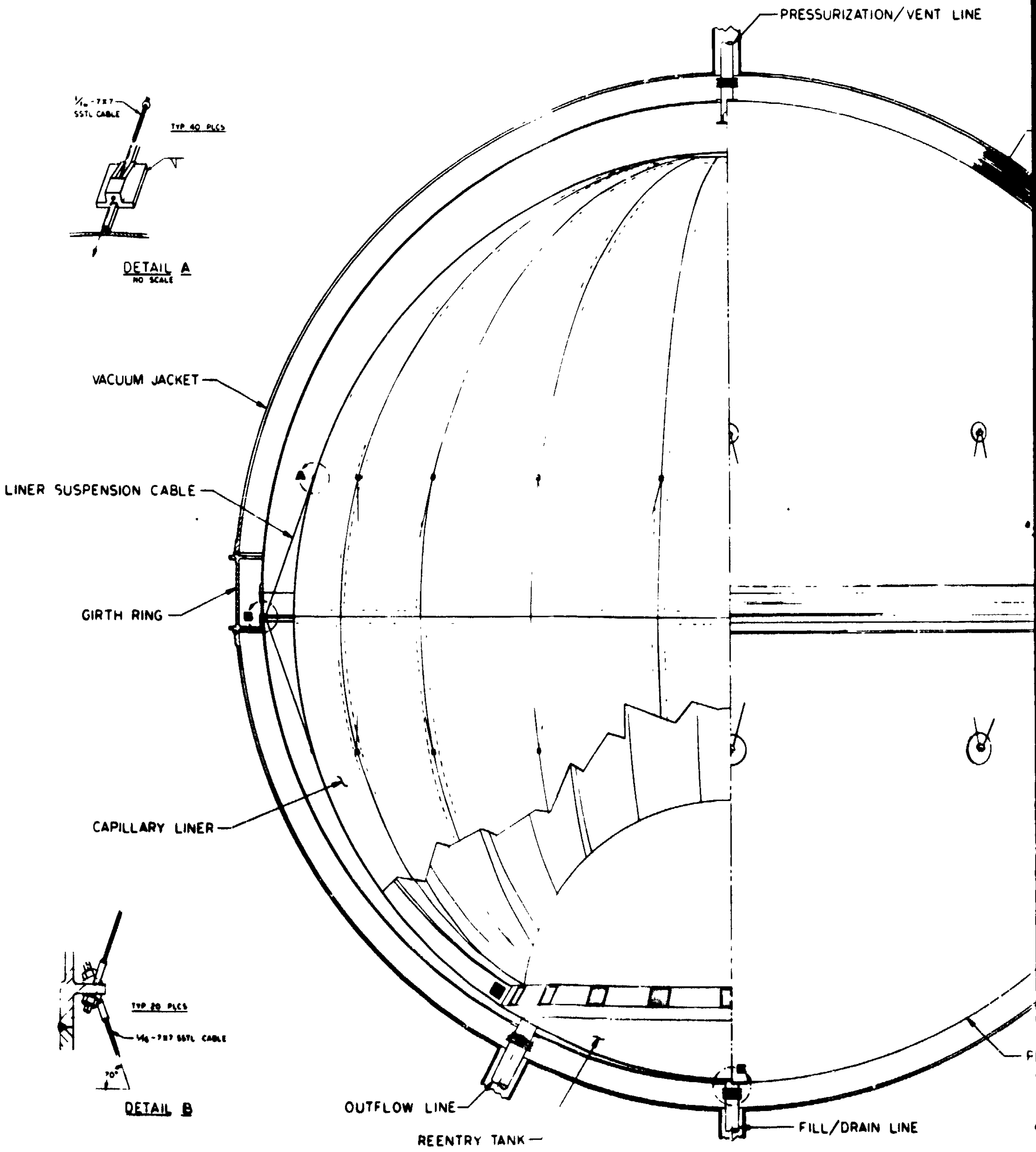

Fig. VII-2 LH_2 Acqu

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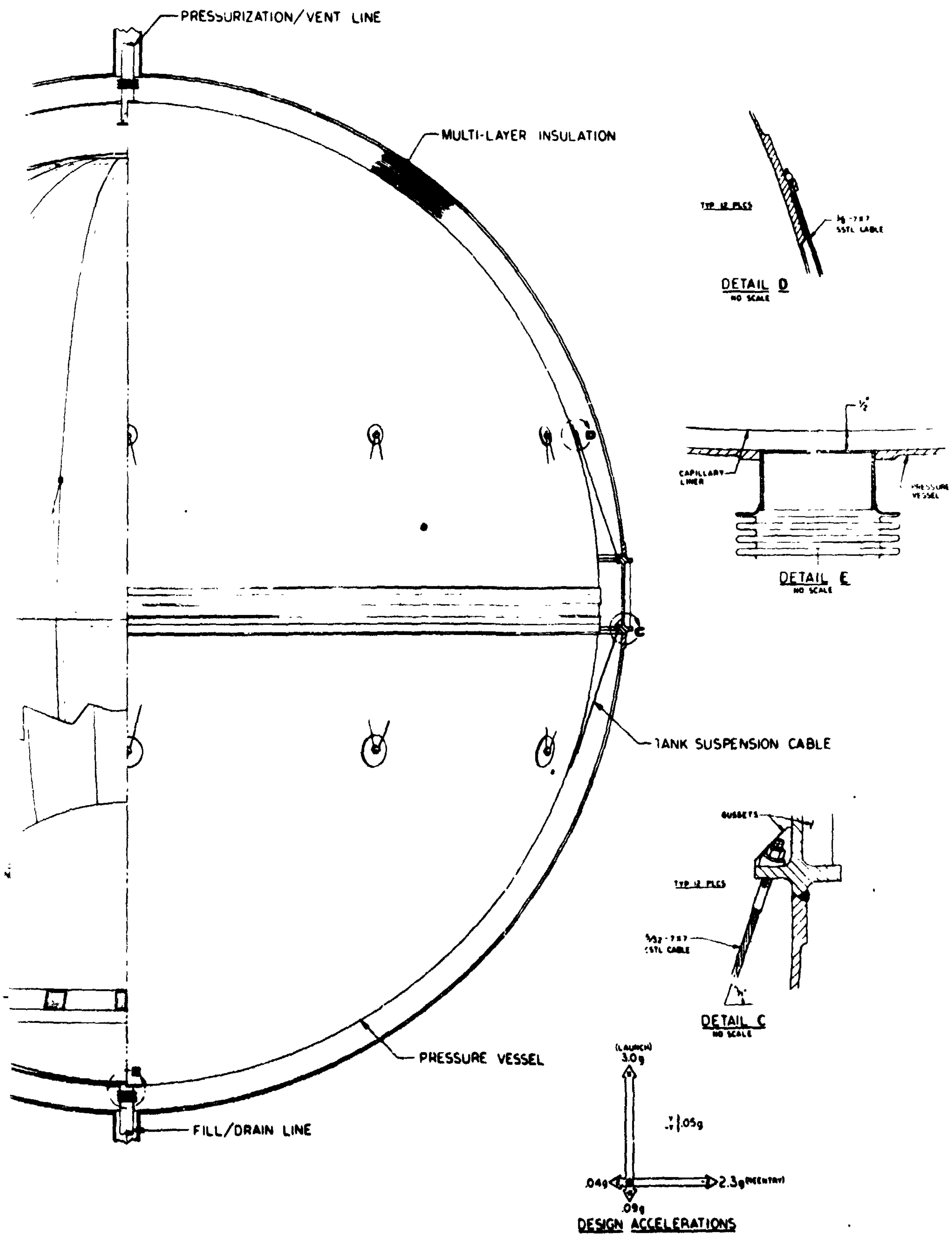

Fig. VII-2 LH_2 Acquisition/Expulsion System and Tank Assembly Details

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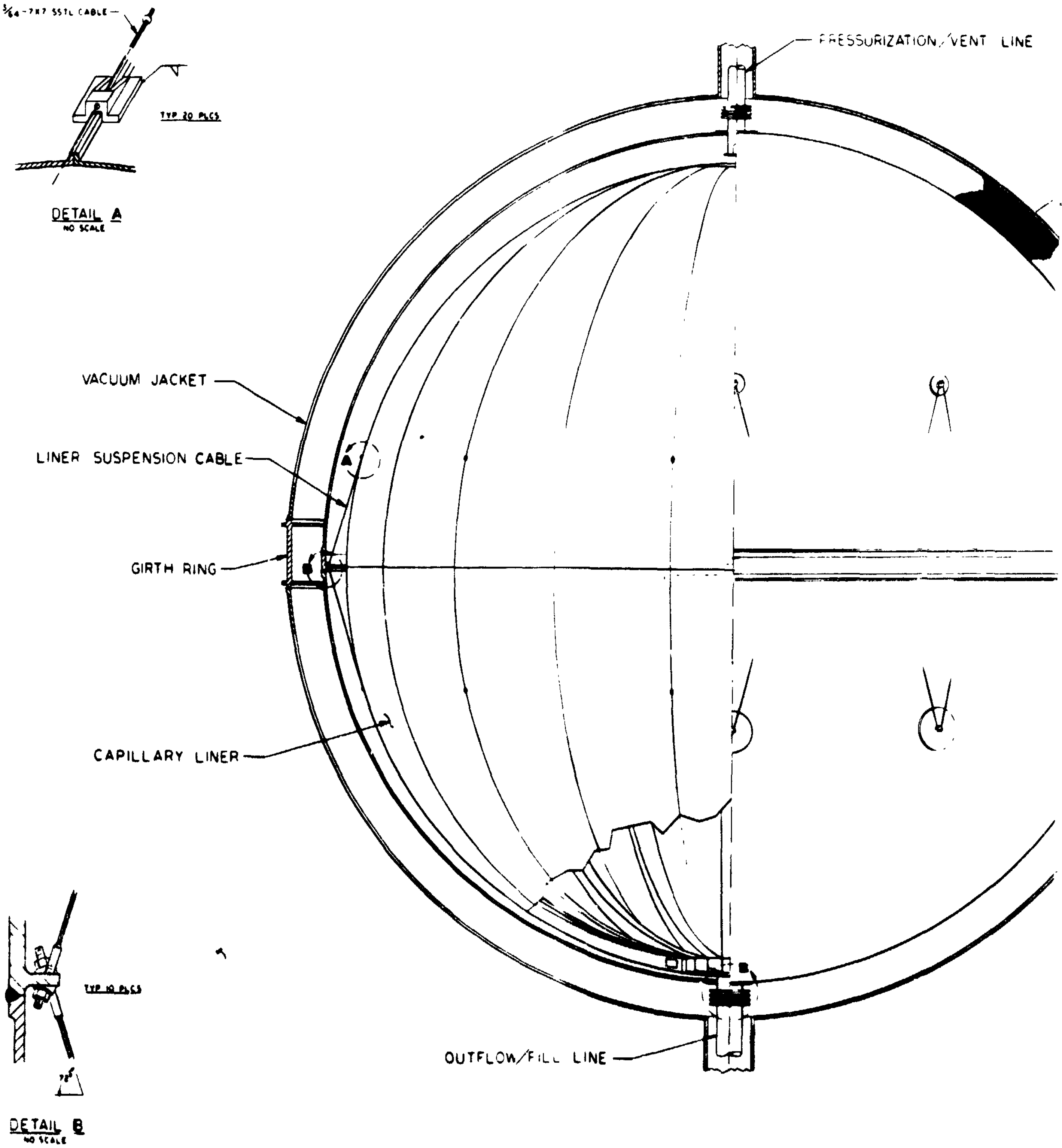

Fig. VII-3 LO_2 Acqui

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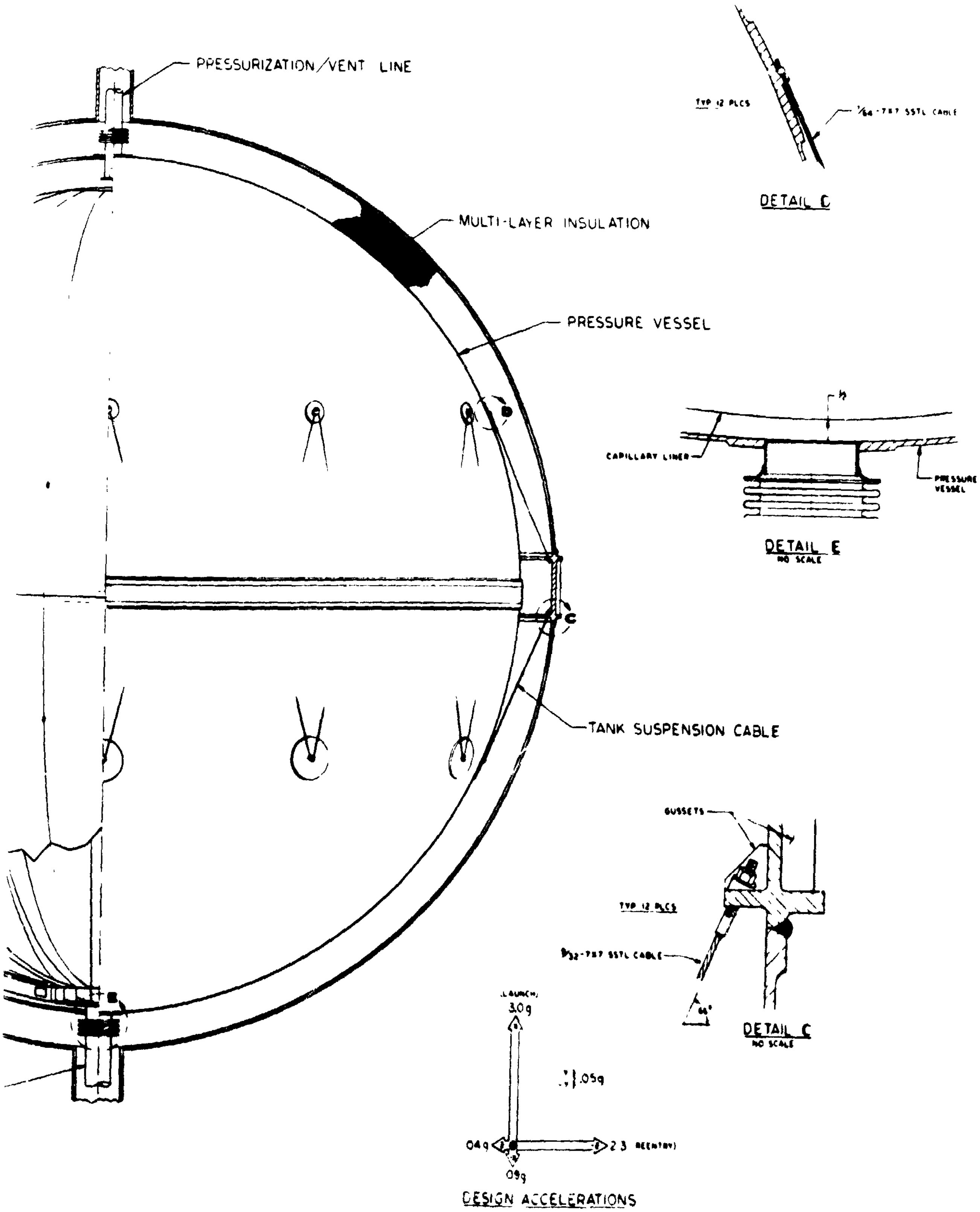

Fig. VII-3 LO_2 Acquisition/Expulsion System and Tank Assembly Details

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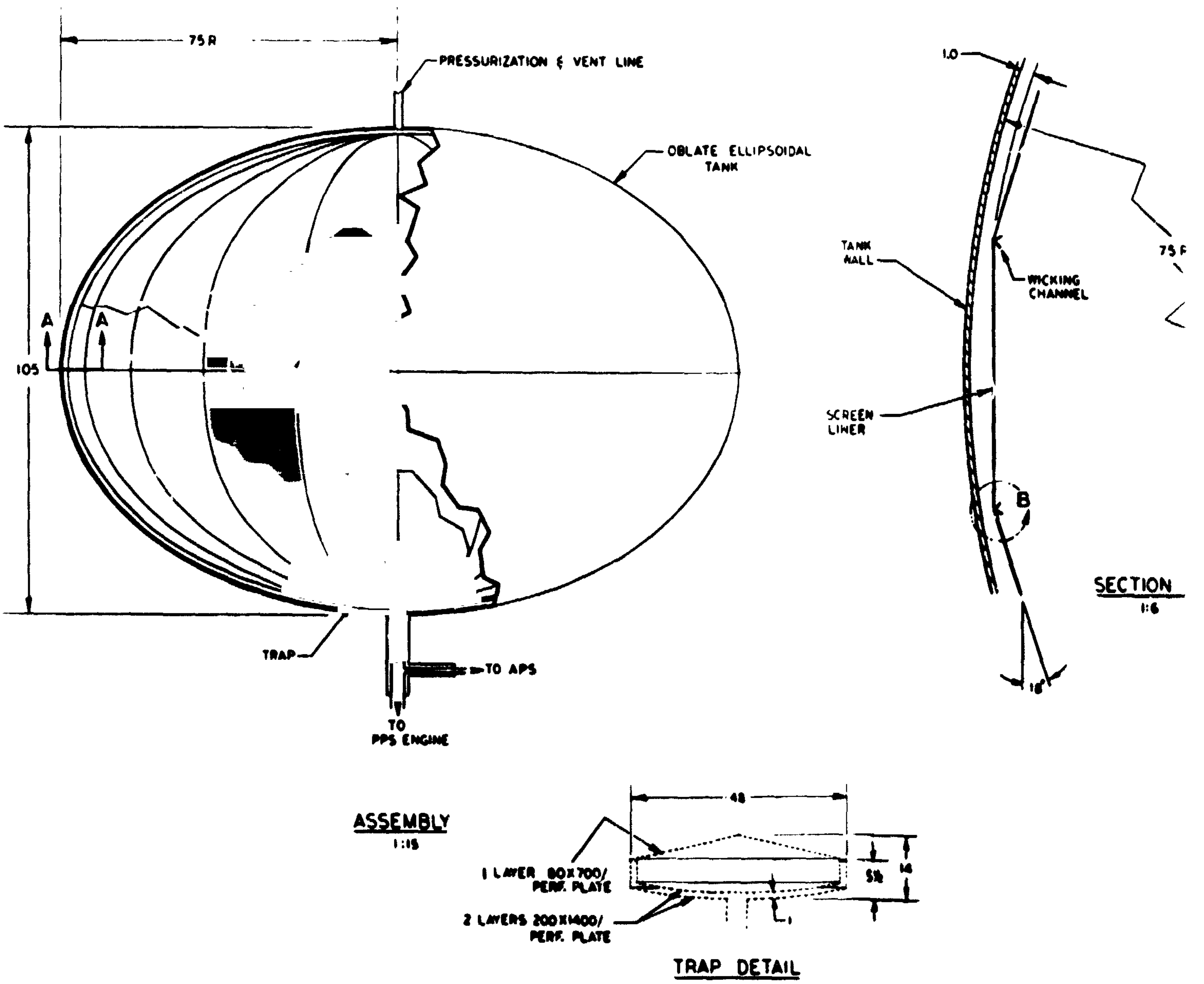

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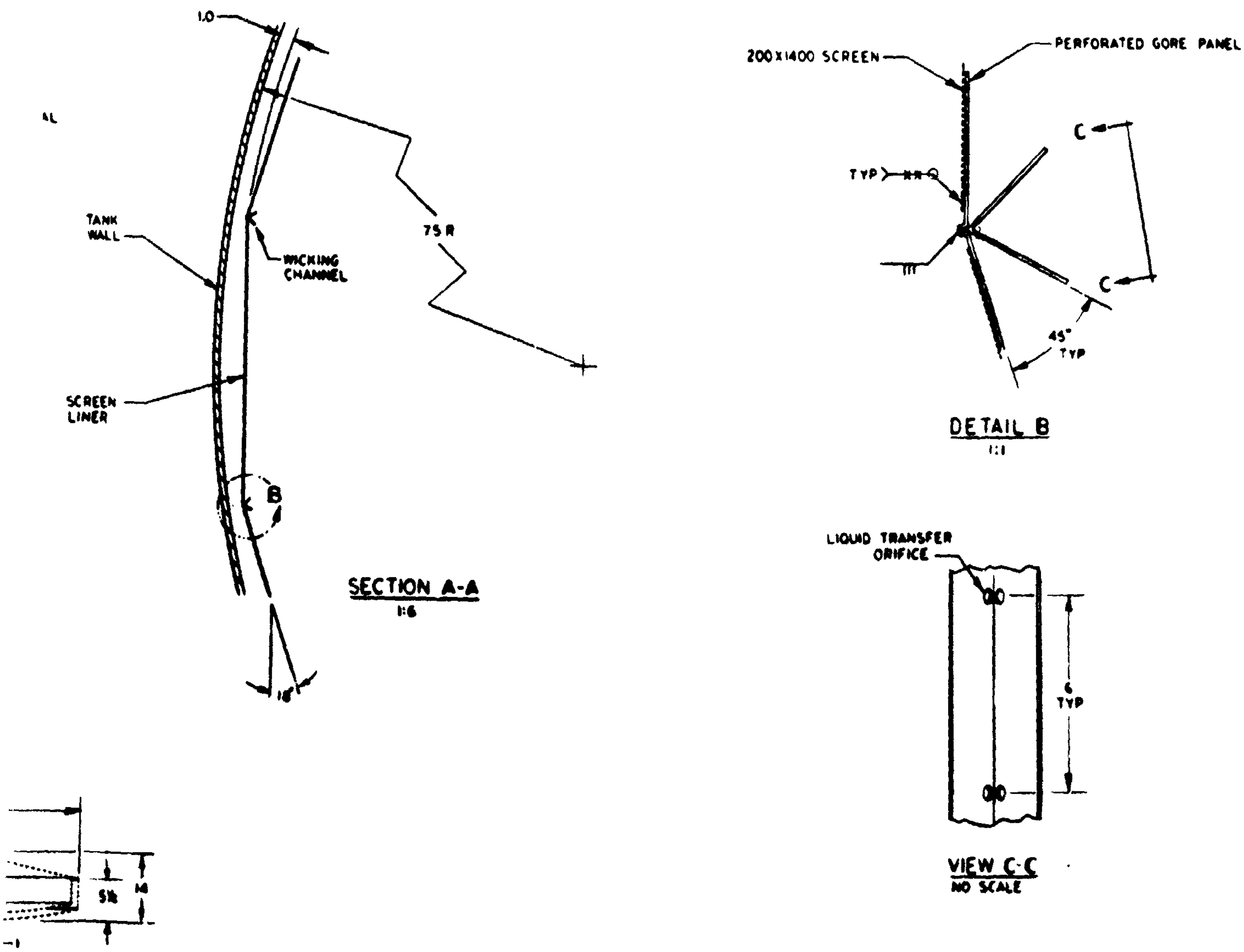

Fig. VII-4 LO_2 Trap System for Space Tug

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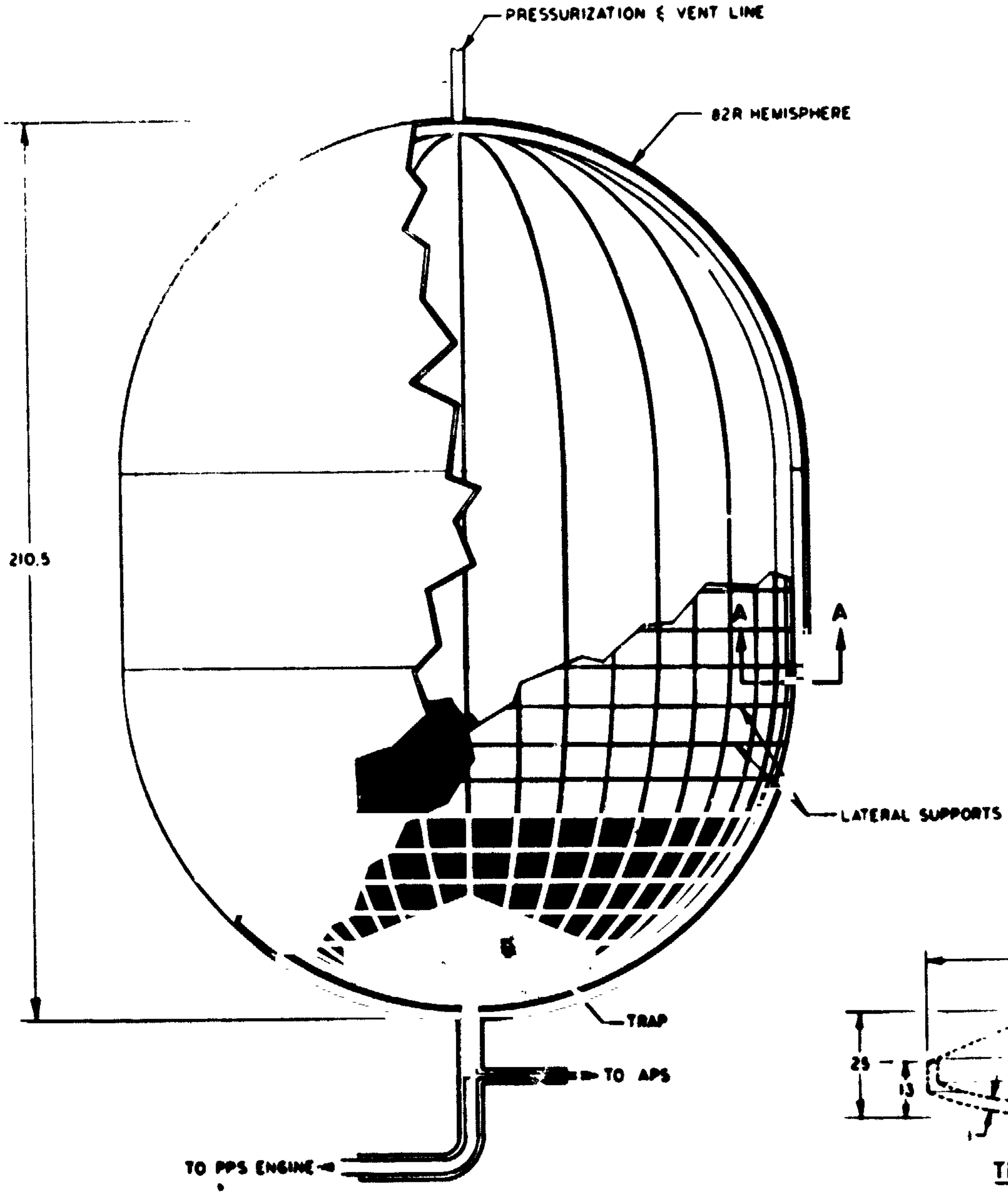

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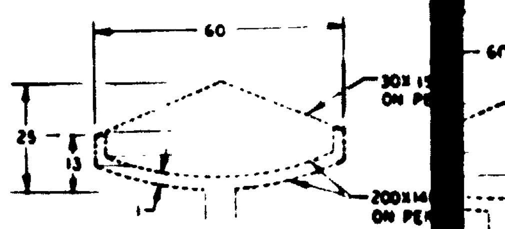

TRAP DETAIL

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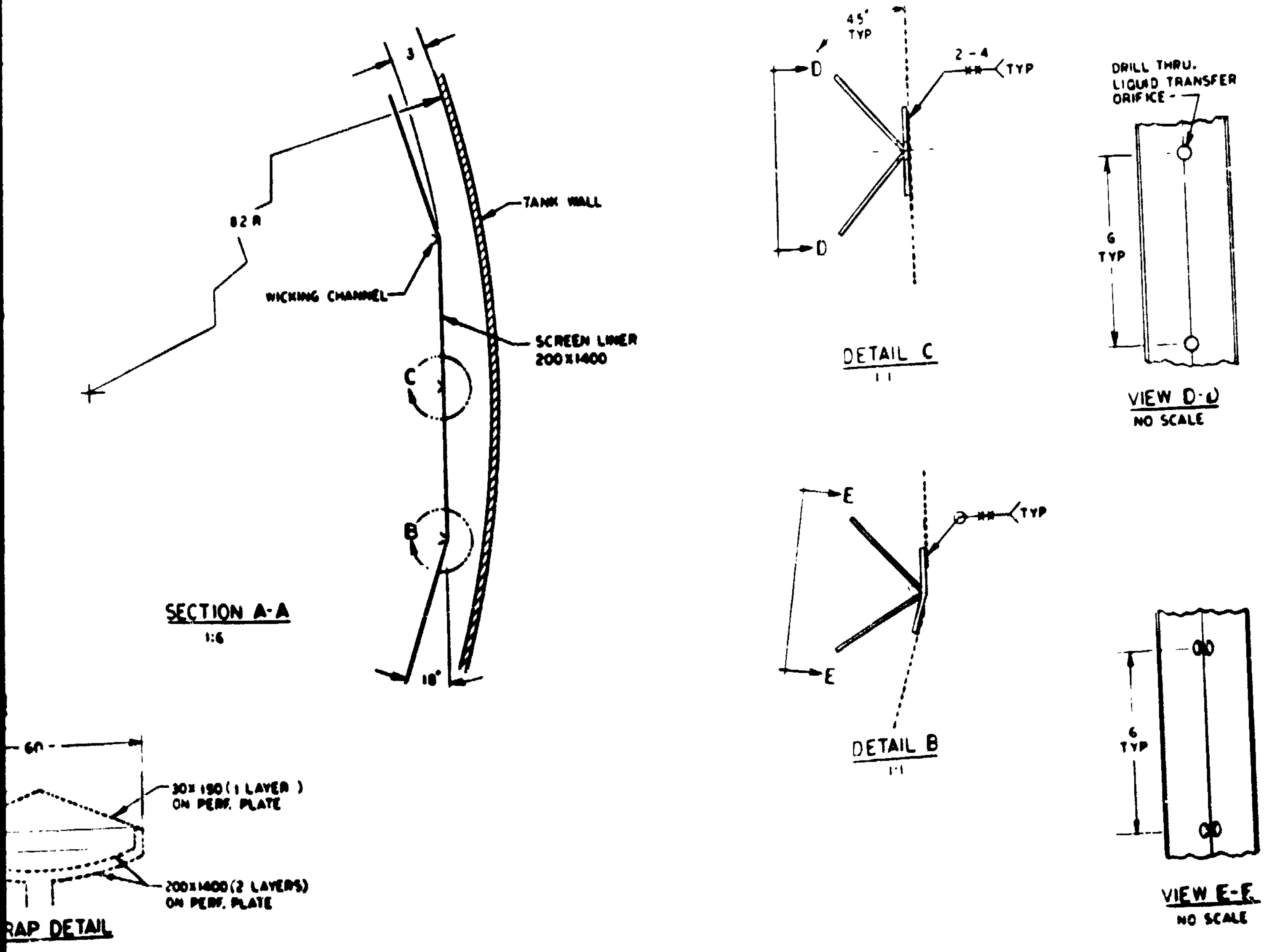

Fig. VII-5 LH_2 Trap System for Space Tug

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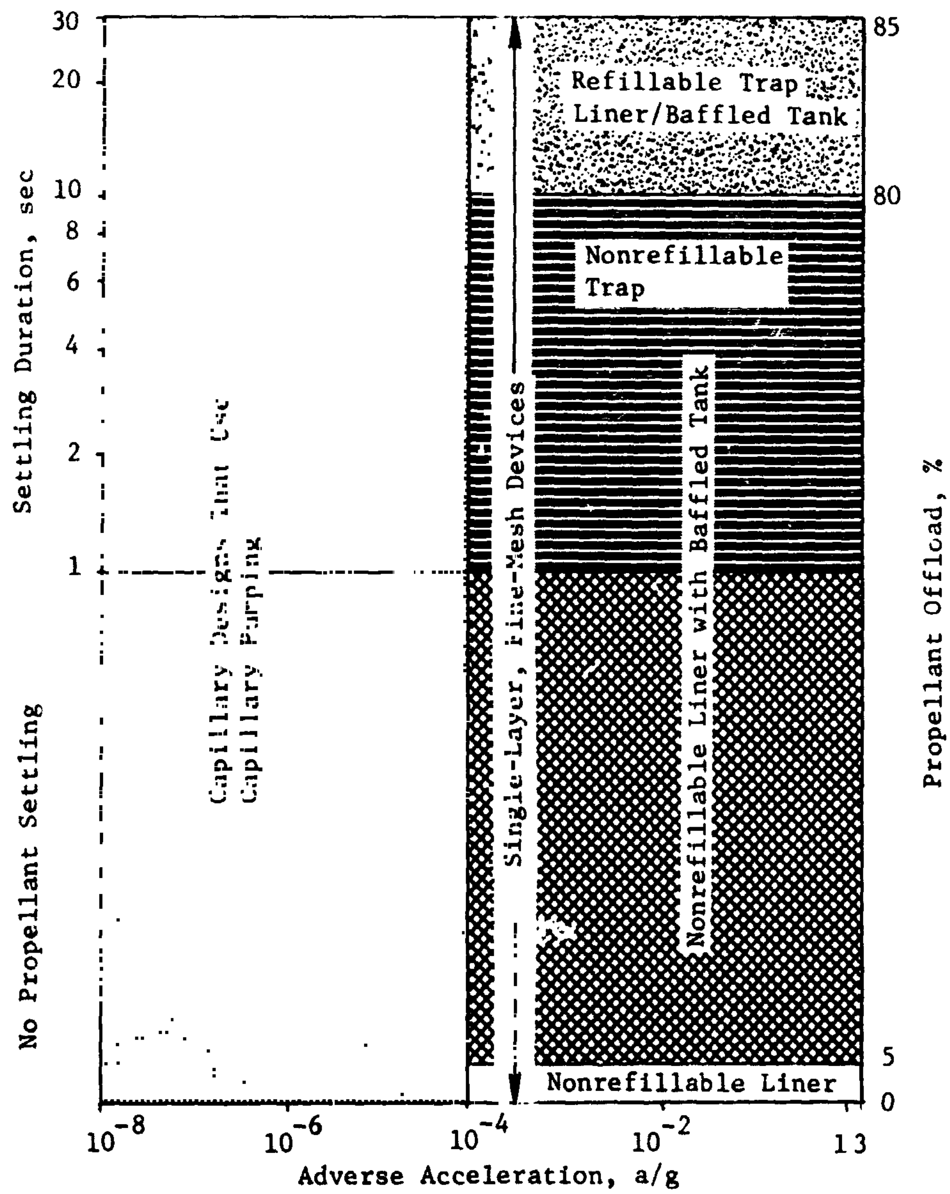
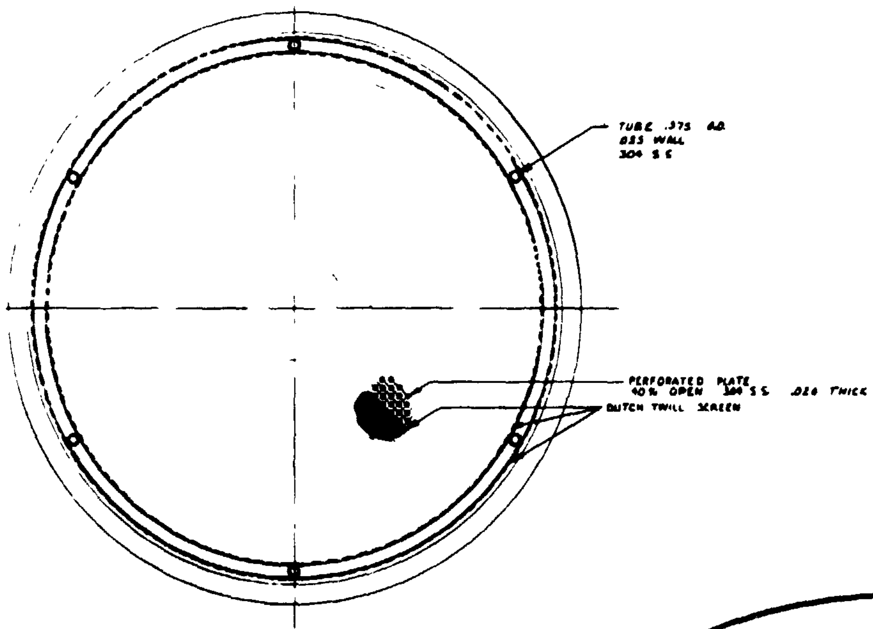


Fig. VII-6 Passive Acquisition/Retention Design Applicability Range

Operational conditions for the typical Shuttle orbiter OMS include RCS maneuvers that may occur at any time on orbit and that contribute random acceleration vectors with magnitudes to 0.026 g. Systems like that used in the Viking Orbiter are, therefore, not applicable for the OMS. Fine-mesh designs, on the other hand, are candidate devices and lie to the right of the 10^{-4} g line; i.e., in the region where the adverse acceleration is greater than 10^{-4} g. These designs may use small traps positioned over the tank outlet (Fig. VII-7) or in the form of channels. The trap system easily handles propellant offloading since it is submerged during launch; however, its size strongly depends on the engine's duty cycle. Since the minimum burn for the representative OMS duty cycles considered during the study was greater than 10 sec, a refillable trap can also be used. The refillable design permits gas to be purged from the trap during expulsion. As a result, it is smaller and lighter than the nonrefillable trap, though both designs are applicable for the OMS. In contrast, the nonrefillable trap does not require burns of 10 sec or longer, but is still dependent on the engine's duty cycle.

The fine-mesh liner is insensitive to the engine duty cycle since it does not rely on propellant settling. It is sensitive to propellant offloading, however, and it may be necessary to use more than one layer of Dutch twill screen or to compartmentalize the tank to satisfy offloading requirements.



SECTION B-B

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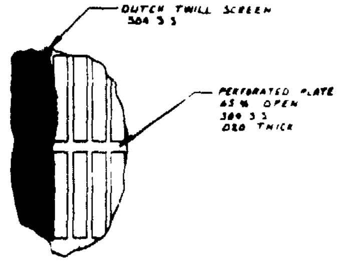

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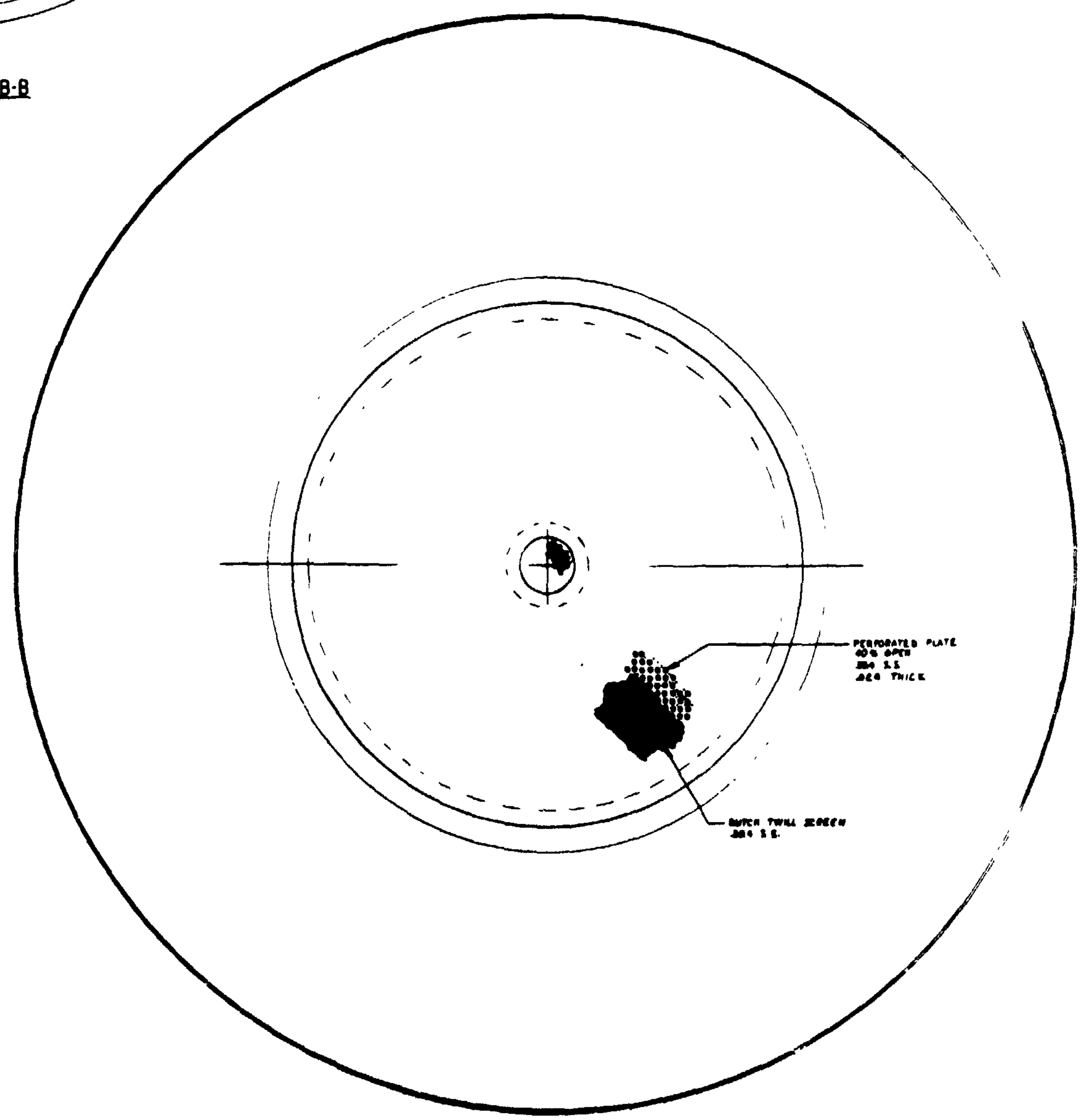

SECTION A-A

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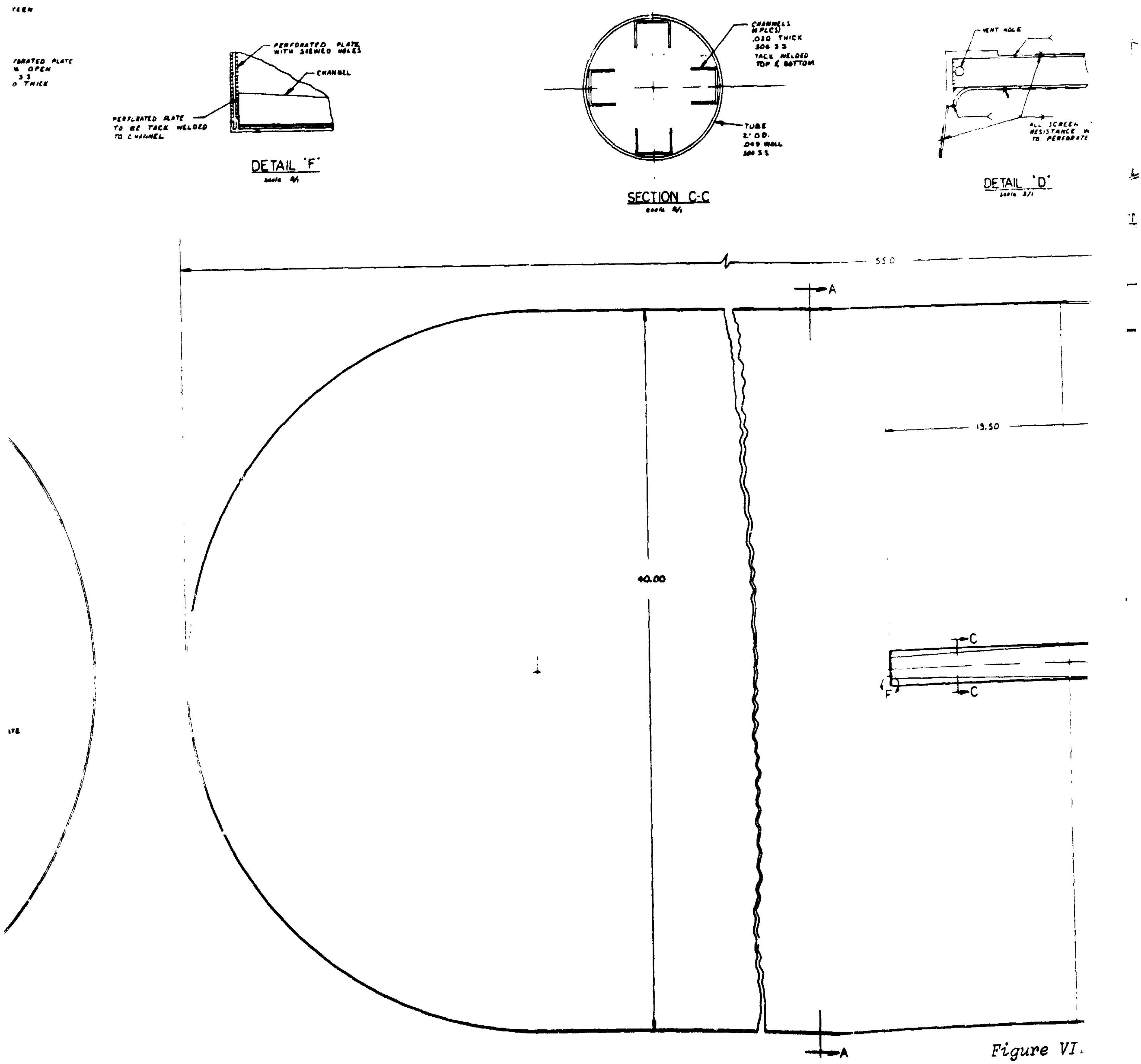

Figure VI.

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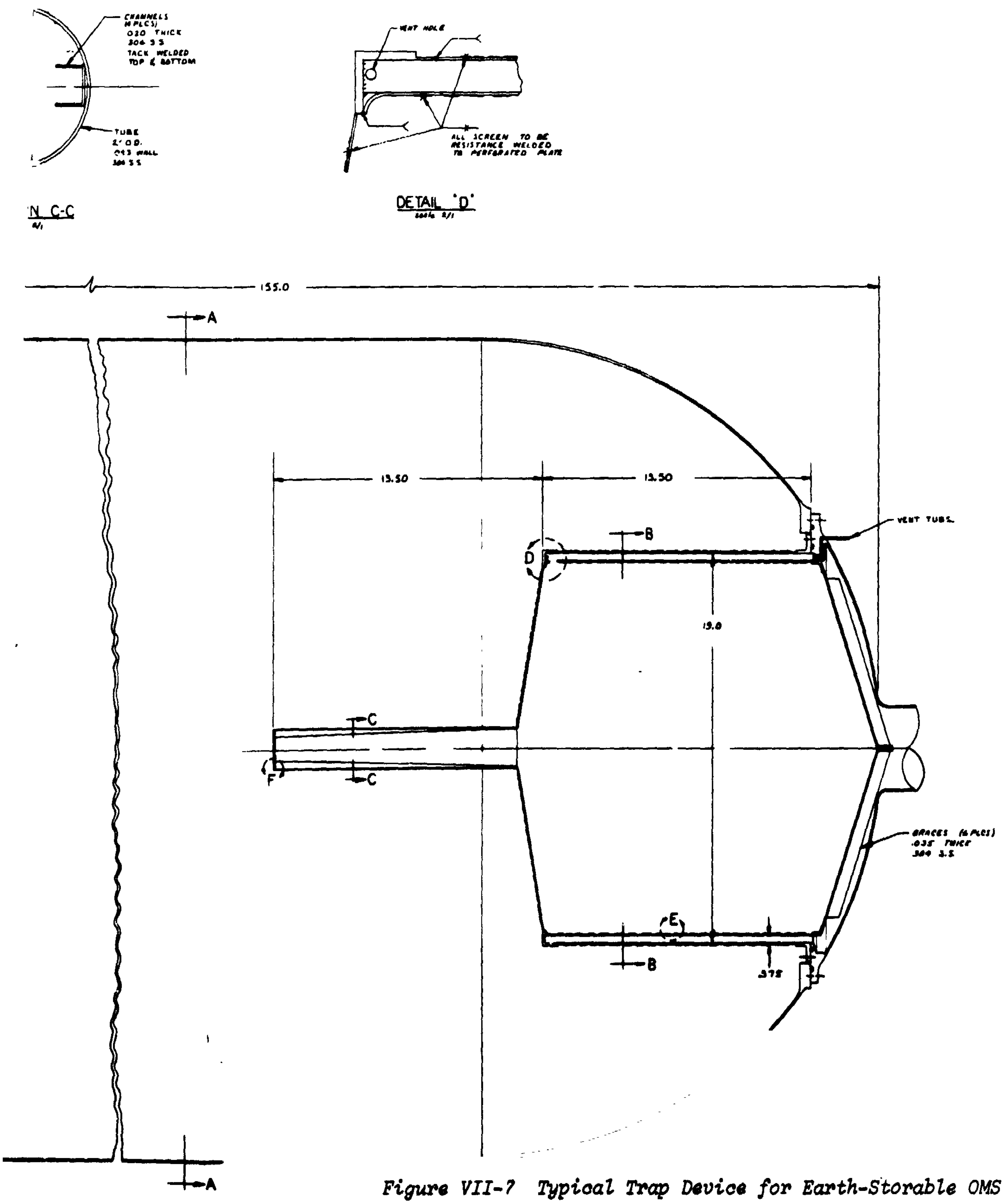

Figure VII-7 Typical Trap Device for Earth-Storable OMS

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VIII. PROGRAM COSTS

The total cost of the program was $594,000.

IX. REFERENCES

I-1 *Passive Retention/Expulsion Methods for Subcritical Storage of Cryogens, Summary Report.* MCR-71-37. Martin Marietta Corporation, Denver, Colorado, July 1971.

V-1 H. L. Paynter, *et al.: Investigation of Space-Storable Propellant Acquisition Devices, Final Report.* MCR-70-171. Martin Marietta Corporation, Denver, Colorado, December 1970, pp IV-22 thru IV-37.

VII-1 *Viking Orbiter 1975 Propellant Management Device, Final Report.* Report No. SE-010-47-01, Contract JPL 953261. Martin Marietta Corporation, Denver, Colorado, May 1973.